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SUSCEPTIBILITY OF STANDS TO DEFOLIATION BY WESTERN SPRUCE BUDWORM ON THE PAYETTE NATIONAL FOREST, IDAHO

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SUSCEPTIBILITY OF STANDS TO DEFOLIATION BY WESTERN SPRUCE BUDWORM ON THE PAYETTE NATIONAL FOREST, IDAHO

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ABSTRACT

A decision tree was constructed to classify stands on the Payette National Forest, Idaho, as to their probability of being defoliated during an outbreak of western spruce budworm. This work is based on 17 years of defoliation records taken during an outbreak which began on the Payette National Forest in 1967 and the Forest's timber stand inventory. The decision tree takes into consideration habitat type series, forest class, elevation, and physiographic site, and predicts the probability of defoliation, top kill, and tree mortality.

INTRODUCTION

The western spruce budworm, Choristoneura occidentalis Freeman, is a native defoliator of Douglas-fir, true firs, and spruce in western North America. On the Payette National Forest in central Idaho, periodic outbreaks of this pest have been documented (Johnson and Denton 1975). The most recent outbreak of western spruce budworm began in the northern part of the forest in 1967 and spread over most of the host type during the next 17 years. Extent and intensity of defoliation varied considerably within the forest. Growth loss, top kill, and mortality resulting from the budworm feeding in several zones have been evaluated and reported by Beveridge and Cahill (1984).

Even though damage has been evaluated, the capability of predicting probability of defoliation and identification of stand factors closely associated with budworm activity is not available. Such a capability would greatly aid land managers in determining where to emphasize and how to prioritize stand management for budworm. Thus, under the sponsorship of the CANUSA-West Spruce Budworms Research and Development Program, an evaluation was begun on the Payette National Forest to develop probability predictors for defoliation and to explain why some stands are subject to greater damage than others during an outbreak of western spruce budworm.

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METHODS

An empirical approach was used to develop a function to predict the probability of defoliation for stands in the Payette National Forest. The data from aerial sketch mapping of the recent outbreak was merged with the timber inventory stand data. A risk function was computed for defoliation through statistical analysis of this joint data base.

Risk Rating and Hazard Rating Systems have been described for both eastern and western spruce budworm (Witter et al. 1984; Carlson et al. 1985). A risk rating system is an index to the susceptibility to the spruce budworm for a stand. A hazard rating system is an index of the vulnerability of the stand. Susceptibility is the probability that a stand will be infested by budworm. Vulnerability is the probability that damage will result to trees when the stand is infested. In this work, hazard rating will be replaced with the estimates of the probability of tree damage by species. The risk rating will be the probability of observed defoliation in the stand rather than the probability that the stand is infested.

DATA SOURCES

This work is based on 17 years of defoliation data collected during aerial sketch map surveys (Beveridge and Knapp 1984) and supplemented by growth data from the forest inventories.

The location of the inventoried stands was matched by computer to the defoliation data. A new data record was then created containing the inventory data by stand (from the timber inventory in the System 2000 data base), and the defoliation rating by year for each of the 17 years for the area where the stand is located.

The stands in the Payette National Forest timber inventory are described by such variables as habitat type series (Steele et al. 1981), forest class, physiographic site, aspect, and elevation.

A habitat type is the aggregation of all land areas potentially capable of producing similar plant communities at climax. The series is identified by the dominant overstory species at climax. The forest class is a classification of the forest land based upon the species forming a plurality of stocking based on area occupied in the present tree cover.

The forest inventory stand data consisted of a probability sampling of stands for a forest. Attributes of these stands can then be used to obtain unbiased estimates of that attribute for the total forest. The attribute can be a defoliation rating or a habitat type series, or the intersection of the two. For example, total acreage, which is in the grand fir habitat type series and is defoliated for more than five years, can be estimated.

A defoliation index was used as a measure of potential impact. The defoliation index is the sum of the defoliation ratings for a stand over the 17 year period. The annual ratings were: 0 - no defoliation; 1 - light

defoliation; 2 - moderate defoliation; and 3 - heavy defoliation. A random sample of stands was stratified by defoliation index and examined for tree damage. The average rate of top kill and tree mortality was computed for each strata by species (Ollieu et al. 1977).

The probability of defoliation was modeled using the forest timber inventory. By combining these analyses, one can predict the probability of a stand of a given description being involved in the outbreak and the defoliation index for such a stand, plus the implied impact in terms of tree damage for stands with such an index value.

STATISTICAL METHODS

Several statistical methods were used in this analysis. Cross tabulation or contingency tables were used to relate discrete variables among themselves or to classes of defoliation measurements. Classification tree analyses are used to explain the budworm impact during the past outbreak on the forest.

The defoliation rating for a stand in any one year was 0, 1, 2, or 3 according to the rating scheme of Ollieu, et al. (1977). The sum of the ratings from each year over the 17 years of the outbreak ranged from 0 to 36. The following were devised to represent degrees of defoliation as seven classes: 0, 1-3, 4-6, 7-9, 10-12, 13-19, 20-36. The seven defoliation classes were then cross checked against the stand descriptor.

Several variables which describe stand conditions are by nature discrete variables. These are habitat type series, forest class, and physiographic site. The continuous variables, aspect and elevation, were put into classes.

The probability of a stand being defoliated during a budworm outbreak should be a function of its stand characteristics. The elevation of the stand, its forest class, and habitat type series each affect the chance that the stand will be included in the outbreak. An empirical estimate of this probability can be obtained as the ratio of similar stands that were defoliated in the last outbreak to the total number of similar stands in the forest. Since our inventory base is derived from a random sample of stands in the forest it can be used to estimate this probability. The problem is how to classify the inventory stands into groups with similar stand descriptions. The variables used to determine the groups should be those that reflect a change in the probability of defoliation so the groups will have different defoliation ratios.

A nonparametric statistical procedure, CART (classification and regression trees), was used to classify the stands from the forest inventory into groups with the same chance of being defoliated. The classification rule is developed in the format of a binary decision tree (Breimen et al. 1984).

The dependent variable in the analysis, Y, took the value "1" if the stand was defoliated during the outbreak and "0" if the stand was not defoliated.

The independent variables were discrete variables indicating presence: 1, or not present, 0; habitat type series: ABGR, ABLA, PSME, and PIPO; forest

class: Douglas-fir, grand fir, Engelmann spruce/alpine fir, ponderosa pine, and lodgepole pine; physiographic site: wet hillside, dry hillside; and the continuous variable elevation.

The CART procedure examines each variable for a condition on which to split the data. The variable which produces the best split separates the data into two groups, each of which is more homogeneous than the total data. In the case of defoliation, homogeneous means that the new groups are composed of one with a greater defoliation ratio and one with a smaller defoliation ratio than the original group. The best split is the one which creates the largest difference in these ratios.

After a split the two groups just created are examined separately with each of the independent variables to find the best split for each. The stopping rules are based on sample sizes and statistical tests on the misclassification ratio (Breimen et al. 1984).

RESULTS AND DISCUSSION

The cross-classification of the stands from the timber inventory, by defoliation ratings and classes of stand descriptor variables, provides some quantitative data to support qualitative statements made in the past about western spruce budworm outbreaks.

Since both forest class and habitat type series provide information on the likely species composition in a stand, they should be related to the defoliation potential for the stand. These two variables do not contain the same information about the stand. Habitat type series is based on potential conditions at climax, whereas forest class is based on present area by tree species.

The habitat type series most frequently found in the inventory from the Payette National Forest were: (1) grand fir, Abies grandis (ABGR); (2) Douglas-fir, Pseudotsuga menziesii (PSME); (3) alpine fir, Abies lasiocarpa, (ABLA); and (4) ponderosa pine, Pinus ponderosa (PIPO) (Table 1).

The cumulative defoliation for stands was not the same for each of the habitat type series. The ABGR series had the lowest percent of stands with no defoliation. This may indicate an adaptation of the budworm to the environment of this habitat or the super abundance of host trees (spruce, Douglas-fir, and true firs) in the habitat type series. The ABGR series also had the greatest percentage of stands in the high defoliation classes (seven and greater). This indicates that severe top kill and tree mortality is more likely in the ABGR habitat type series than the others.

By contrast, the other prominant series, ABLA and PSME, had 50 percent or more of their stands without defoliation during the outbreak period.

Table 1: Cumulative western spruce budworm defoliation by habitat type series - Payette National Forest, Idaho.

DTOTAL[1/]	Percent of Stands by Defoliation Class in Each Habitat Type Series			
	ABGR	ABLA	PIPO	PSME
0	14.2	50.6	62.5	50.3
1-3	12.0	18.3	25.0	22.4
4-6	9.3	7.8	12.5	5.4
7-9	9.8	4.4		3.0
10-12	13.6	3.3		6.1
13-19	24.6	6.1		5.4
20-36	16.4	9.4		7.3
Column Total Number of Stands	183	180	8	165

[1/]This is the sum of the defoliation ratings for the stand over the 17 years of the outbreak.

The grand fir forest class, no doubt also ABGR habitat type series, had over 70 percent of its stands in heavy defoliation classes, seven or greater. In contrast, the lodgepole pine forest class had only 18 percent of its stands with this level of defoliation (Table 2).

Although the forest class of a stand may be identified by a nonhost species, it can still contain a component of host trees and be defoliated by western spruce budworm. For example, a stand may be 30 percent in ponderosa pine, 25 percent in grand fir, 25 percent in Douglas-fir, and 20 percent in alpine fir. Such a stand would be classified as ponderosa pine forest class while 70 percent of the area is occupied by host species of the western spruce budworm. This may explain why the ponderosa pine forest class shows a similar defoliation pattern to the Douglas-fir and the Engelmann spruce/alpine fir classes.

Table 2: Cumulative western spruce defoliation class by forest class - Payette National Forest, Idaho.

DTOTAL[1/]	Percent of Stands by Defoliation Class in Each Forest Class					
	Douglas-Fir	Ponderosa Pine	Grand Fir	Engelmann Spruce	Subalpine Fir	Lodgepole Pine
0	39.5	41.3	11.2	11.1	39.2	60.6
1-3	24.1	15.5	5.6	11.1	19.6	18.2
4-6	6.8	8.7	10.1	11.1	8.8	3.0
7-9	2.5	7.8	11.2		3.9	9.1
10-12	9.9	7.8	11.2	44.4	4.9	
13-19	8.6	9.7	29.2		8.8	7.6
30-36	8.6	8.7	21.3	22.2	14.7	1.5
Column Total Number of Stands	162	103	89	9	102	66

[1/]This is the sum of the defoliation ratings for the stand over the 17 years of the outbreak.

A cross tabulation of stands by forest class and habitat type series is given in Table 3. Twenty percent of the stands in the grand fir habitat type series were in nonhost forest classes. Thirty-two percent of the stands in the subalpine fir habitat type series, and 50 percent of the stands in the Douglas-fir habitat type series were in nonhost forest classes. These stands most likely had a host component as indicated by their habitat type series, but were in a serial stage of succession as indicated by their forest class. Defoliation by western spruce budworm can occur in these stands.

Stands which were in the outbreak at its beginning may have a greater chance for a high cumulative defoliation rating than stands that were infested later. For this reason only stands that were defoliated during the first five years were examined next. In Table 4 these stands are classified by forest class and defoliation classes. A similar pattern is seen, as with Table 2 when all stands were considered. The defoliation in the grand fir forest class is much greater than in the Douglas-fir or alpine fir classes. One can conclude that there has been sufficient time for the budworm to spread to all stands in the forest.

The relation of aspect to defoliation is displayed for two elevation zones (Table 5). A more pronounced effect of aspect was seen at the higher elevation zone. There appeared to be less of a change between elevation zones with respect to aspect than there was with respect to physiographic site (Table 6).

The CART procedure was used to classify the inventory stands into groups with similar observed defoliation records. Stand variables were selected to represent the smallest number of questions one must answer to place the stands into homogeneous groups.

The resulting classification tree for the chance of budworm defoliation is given in Figure 1. There are six branching points shown as circles and seven nodes shown as rectangles. Each branching point represents a binary question. The answer determines if a stand should move to the left or right of this point on the decision tree. The numbers in circles and rectangles represent the number of stands in the inventory which fit the conditions for that tree location. The number of stands without defoliation always occurs above the number of stands with defoliation.

The decision tree begins in the upper right corner of Figure 1. At this decision point there are 205 stands in the inventory without defoliation and 338 stands with some defoliation. The entire forest inventory is one group.

The first binary question is, "Is the stand in the ABGR habitat type series?" If yes, the stand moves to the right; if no, the stand moves to the left on the tree. In the inventory there were 183 stands in the ABGR habitat type series; of these, 26 had no defoliation and 157 were defoliated.

The second binary question is asked only of those stands that remained at the first branching point, these stands are not in the ABGR habitat type series. There are 179 stands without defoliation and 181 stands with defoliation at this point.

Table 3: Habitat type series and forest class, Payette National Forest, Idaho.

Habitat Series	Percent of Stands in the Forest Inventory by Forest Class in Each Habitat Type Series			
	ABGR Grand Fir	ABLA Subalpine Fir	PSME Douglas-Fir	PIPO Ponderosa Pine
Forest Class				
Df	30.6	11.2	49.4	--
PP	15.5	.5	44.9	100
Gf	42.7	1.6	--	--
ES	2.4	3.2	--	--
ES/SAF	3.9	52.1	--	--
LPP	3.9	27.5	4.5	--
Other	1.0	3.7	2.2	--
Column Total Number of Stands	206	188	178	8

Table 4: Cumulative western spruce budworm defoliation class by forest class for stands included in first five years of outbreak, Payette National Forest, Idaho.

	Percent of Stands by Defoliation Class in Each Forest Class				
	Df	PP	GF	ES/SAF	LPP
DTOTAL[1/]					
1-3	34.6	13.8	1.0	30.3	41.2
4-6	9.6	13.8	4.9	12.1	5.9
7-9	1.9	10.3	7.3	6.1	29.4
10-12	15.4	13.8	4.9	15.1	0
13-19	15.4	20.7	51.2	9.1	23.5
20-36	23.1	27.6	31.7	27.3	0
Column Total Number of Stands	52	29	41	33	17

[1/]This is the sum of the defoliation rating for the stand over the 17 years of the outbreak.

Table 5: Cumulative western spruce budworm defoliation by aspect and elevation zones, Payette National Forest, Idaho.

	Percent of Stands by Defoliation Class in Each Aspect by Elevation Zone							
	N	NE	E	SE	S	SW	W	NW
Elevation Zone: 6000' < Elevation ≤ 8000'								
DTOTAL[1/]								
0	29.4	48.0	51.9	50.0	60.0	59.1	26.8	54.2
1-3	23.5	16.0	22.2	18.4	15.0	22.7	19.5	16.7
3+	47.1	36.0	25.9	31.6	25.0	18.2	53.7	29.1
Total Number of Stands	17	25	27	38	20	22	41	24
Elevation Zone: 4000' < Elevation ≤ 6000'								
0	30.3	28.9	11.1	24.1	26.9	35.3	36.5	37.5
1-3	24.2	10.5	16.7	13.8	19.2	11.8	9.6	25.0
3+	45.5	60.6	72.2	62.1	53.9	52.9	53.9	37.5
Total Number of Stands	33	38	36	29	26	34	52	40

[1/]This is the sum of the defoliation ratings for the stand over the 17 years of the outbreak.

Table 6: Cumulative western spruce budworm defoliation by physiographic site and elevation zones, Payette National Forest, Idaho.

Physiographic Site	Percent of Stands by Defoliation Class in Each Physiographic Site and Elevation Zone							
	Ridge Top	Wet Hillside	Dry Hillside	Wet Flat	Dry Flat	Rolling	Broken	Bottom of Draw
Elevation Zone:	6000' < Elevation ≤ 8000'							
DTOTAL[1/]								
0	22.2	27.5	53.9	37.5	60.0	66.7		85.7
1-3		20.3	20.0	25.0	40.0	16.7		
3+	77.8	52.2	26.1	37.5		26.7	100	14.3
Total Number of Stands	9	69	115	8	5	12	2	7
Elevation Zone:	4000' < Elevation ≤ 6000'							
DTOTAL								
0	36.4	17.0	38.7		77.8			38.5
1-3	18.2	18.9	14.8			33.3		7.7
3+	45.4	64.1	46.5	100.0	22.2	66.7	100.0	53.8
Total Number of Stands	11	106	142	6	9	6	3	13

[1/]This is the sum of the defoliation ratings for the stand over the 17 years of the outbreak.

The question for these stands is, "Is the stand elevation lower than or equal to 6,850 feet?" Those stands over 6,850 feet move to the right, those at or lower than 6,850 feet move to the left. There are 89 stands in the inventory over 6,850 feet. Of these 65 were not defoliated, 24 were defoliated. We also know from the first branch that none of these stands are in the ABGR habitat type series.

The next decision point for stands lower than 6,850 feet elevation is a question of forest class; "Is the stand in the Engelmann spruce-alpine fir forest class?" There were 51 stands which moved to the right, being of this forest class, and of these, 46 were defoliated. This gives a high probability of defoliation, 0.90, for these stands.

The remaining 220 stands are next split on the physiographic site variable. The question is, "Is the stand on a wet hillside?" The "Wet Hillside" class contained 47 stands of which 33 were defoliated. It must be remembered that these stands, in addition to being located on wet hillside condition are not ABGR habitat type series, nor ESAF forest class, and are lower than 6,850 feet.

The next two splits of the data are on elevation. Those stands below 4,950 feet form a separate group with a low probability of defoliation 0.32 (23 stands defoliated of 72). The mid-elevation group is those stands over 4,950 and less than 5,950 feet. The probability of defoliation for this group is 0.68 (32 stands of 47). The last group is a little higher in elevation, >5,950, and has a probability of 0.43 of defoliation. This last group could be further split, but the stand sample size becomes too small to ensure confidence in the estimated probability.

The last two splits were subject to the conditions specified in earlier splits of the data. This imposes an elevation boundary of stands lower than 6,850 on the last group defined. In addition, these stands are not ABGR habitat type series, ESAF forest type, or wet hillside physiographic type.

The nodes on the decision tree determine the groups for which an empirical probability of defoliation can be estimated. The seven groups are identified as A through G in Figure 1.

Stands in Group A fit the following description. They are not ABGR habitat type series, not Engelmann spruce/alpine fir forest type, not on wet hillsides; they are at or below 4,950 feet. There are 72 such stands in the inventory and 49 of these were not defoliated. The empirical estimate of the defoliation probability is 0.32 based on these stands.

Group E, by contrast splits off at the third decision point. The stands in this group are Engelmann spruce/alpine fir forest class, but they are not in the ABGR habitat type series and lie below 6,850 feet. There were only 51 stands in this group, but 46 of these were defoliated. The empirical estimate of defoliation probability is 0.90 for this group.

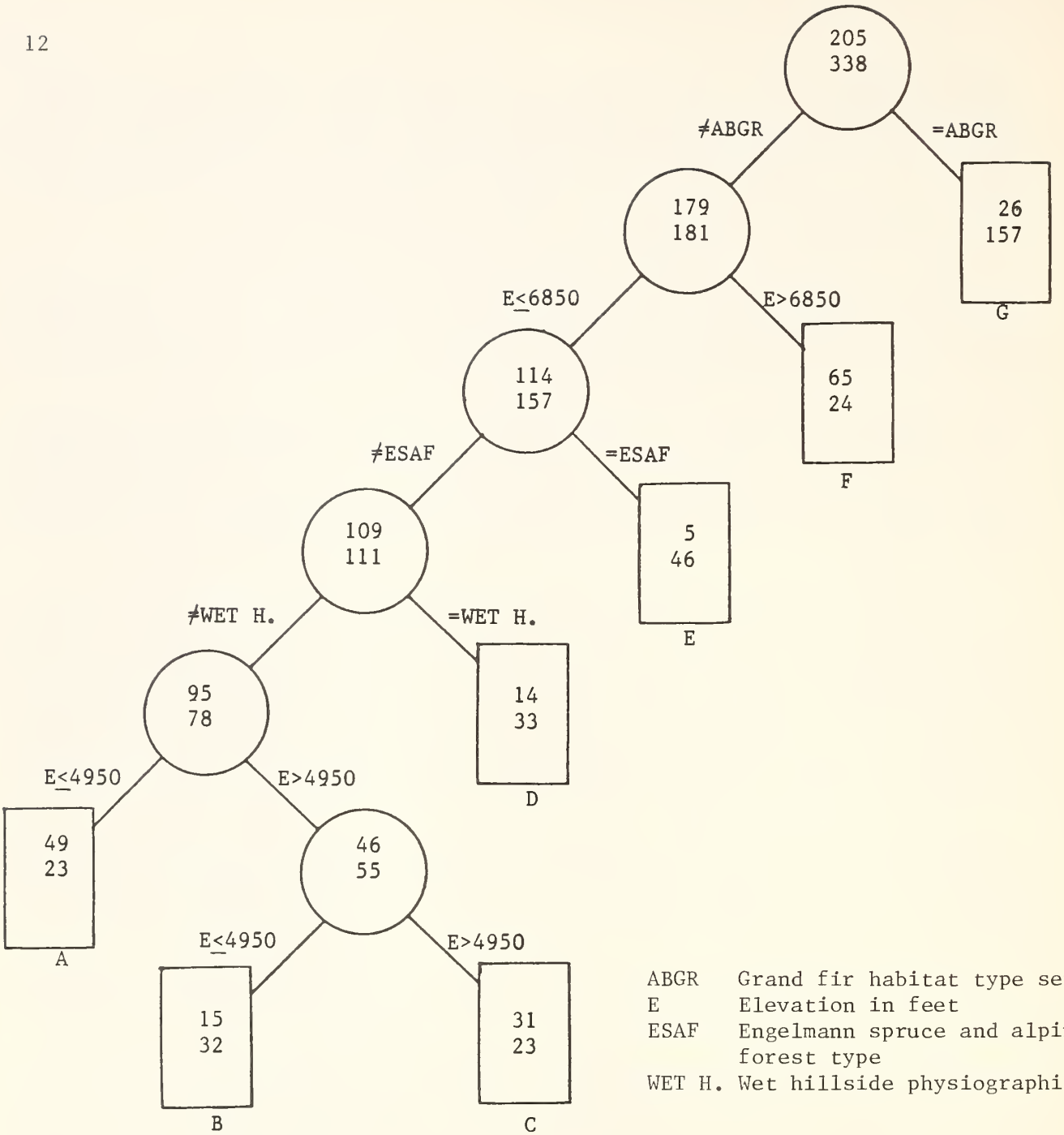

Figure 1: Decision tree for classification of stands as defoliated or not defoliated on the Payette National Forest, Idaho. (At each node and branching point the number of stands without defoliation appears above the number of stands with defoliation.) The letter (A-G) placed below each box is the group name.

The classification rule derived using CART gives a method of placing a stand into a group with an observed rate of inclusion in the spruce budworm outbreak. We can further describe these groups in terms of the degree of defoliation found in them.

The defoliation rating for a stand summed over several years of the outbreak has been related to stand damage (Ollieu et al. 1977; Beveridge et al. 1978).

As defoliation continues for several years it causes reduced radial and height growth, top kill, and even tree mortality. To measure the association between the cumulative defoliation index and tree damage, stands were grouped into classes or analysis units using the cumulative index. These classes were then sampled and the tree damage for these sampled stands recorded. Table 7 is based on data from Ollieu, et al. (1977).

Table 7: Grouping of stands by cumulative westerm spruce budworm defoliation, Payette National Forest, Idaho.

Analysis Unit	Cumulative Defoliation	Defoliation Intensity
1	0	none
2	1-6	light
3	7-12	moderate
4	13-22	heavy
5	>22	severe

Table 8: Number of stands by western spruce budworm defoliation rating by group (7 groups), Payette National Forest, Idaho.

GROUP NAME	Probability of Defoliation (P)	No. of Stands (N)	Analysis Units (1)	(2)	(3)	(4)	(5)
A	.32	72	49	14	6	2	1
B	.68	47	15	12	7	6	7
C	.43	54	31	15	3	4	1
D	.70	47	14	18	5	7	3
E	.90	51	5	23	4	13	6
F	.27	89	65	15	7	2	0
G	.86	183	26	39	43	51	24

In analysis units 3, 4, and 5, substantial impacts have been observed. For trees greater than 5 inches dbh, the grand fir (37 percent) and alpine fir (36 percent) have the greatest frequency of top kill (Ollieu et al. 1977). The other major host species had less top kill, Douglas-fir (9 percent) and Engelmann spruce (12 percent). Top kill was also observed among the trees less than 5 inches dbh; grand fir (30 percent), alpine fir (34 percent), Engelmann spruce (12 percent), and Douglas-fir (10 percent).

Some tree mortality (1-2 percent) among trees larger than 5 inches dbh, was attributed to the budworm in analysis units 3, 4, and 5.

The stand frequency from our inventory was subdivided by groups from the CART analysis and the analysis units in the impact analysis by Ollieu et al. (1977) (Table 8). Column 1 represents the groups, A-G, as defined in Figure 1. This is followed by P, the empirical estimate of the defoliation probability in column 2, and N the number of stands in column 3. The analysis units form the next five columns: The frequency of stands in the inventory by each analysis unit and probability group fills out the table.

The grand fir habitat type series, Group G, had a high frequency of stands in analysis units 3 to 5. This indicates a likelihood for severe damage, top kill, and mortality. This group also has a high probability of being in the outbreak P=0.86.

The Engelmann spruce/alpine fir stands at elevations below 6,850 feet, Group E, have a high probability of being defoliated, P=0.90; however, only 23 of 52 stands fall into analysis units 3 to 5. Less severe damage is expected to stands in this group even though there is a high probability of its being a part of the outbreak.

CONCLUSION

Using habitat type series, forest class, elevation, and physiographic site, stands in the Payette National Forest can be classified as to their probability of being defoliated during an outbreak of western spruce budworm. This risk rating classification rule can be expressed as a simple decision tree. These classifications may be increased in depth as we increase the data pool and refine data collecting methods. This data pool will increase as we complete similar surveys on the Boise and Lolo National Forests and add increment core readings and closer control on habitat typing.

Degree of defoliation has been related to tree damage. This paper completes the link between stand characteristics and impacts of western spruce budworm. The stand characteristics used here may be refined, modified, or increased in numbers, as mentioned, with data collected from other forests.

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